ANALYTICAL METHODS FOR THE CONSERVATION OF THE BUDDHIST TEMPLE II OF KRASNAYA RECHKA, KYRGYZSTAN

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Abstract
The methods employed for selecting the repair material for the Buddhist temple II of Krasnaya Rechka, a site located in the upper Chuy Valley, Kyrgyzstan, are described. The temple is built of mud brick and was excavated during several campaigns between 1938 and 1998 with no provision being made for conservation. The first emergency protective measures were initiated in 2003 during a UNESCO project that included other sites located in the Chuy valley. Most of the eroded walls of the temple were given a temporary shelter coat of mud bricks, a method that has proved effective. The main problem after proving the shelter coat was how to assess the repair material for future conservation work (it is planned to repeat the application of the shelter coat, but with materials with improved performance). Assessment was carried out after extensive laboratory analysis of both historic and repair materials, but also after test wall construction and monitoring. The methods explained here could be of use to conservators working in similar projects in the Middle East or Asia.

INTRODUCTION

The Project

The UNESCO Project (2003-2007) is funded by the Japanese Trust Fund for the Preservation of World Cultural Heritage and is part of a wider involvement in the conservation of earthen structures and archaeological sites in Central Asia. Three Silk Road sites (Krasnaya Rechka, Ak Beshim and Burana) are included in the project, whose objectives are [1]:

- Documentation and research. Carry out scientific recording, documentation and mapping at the three sites, and set up a computer-assisted scientific documentation system;
- Conservation. Based on the results of the documentation and research activities, ensure the preservation of major parts of the Krasnaya Rechka site and its protection for present and future generations, as well as emergency safeguarding at Ak Beshim and Burana;
- Master plan. Draw up a master plan for the preservation of the cultural heritage sites along the Silk Roads in the upper Chuy valley in Kyrgyzstan;
- Training. Enhance national and local capacity for the management, preservation and conservation of the cultural heritage through the provision of training to national experts and craftsmen, in conformity with international standards;
- Promotional activities, reporting and publication.

Similar to the Otrar project in Kazakhstan [2], the project was locally managed by a UNESCO national coordinator. Several national partners were involved from the most relevant institutions such as: the Academy of Sciences, Museum of History, Kyrgyzrestaurazia, the Slavonic University, and the Kyrgyz State University of Construction, Architecture and Transport. Selection of trainees was done in such a way as to have several disciplines represented: architect, engineer, archaeologist, historian, conservation chemist, and geologist. The group was trained in documentation activities (recording with total station and photography) and conservation activities (damage assessment, conservation proposal, conservation intervention, laboratory analysis). All training activities took part either at the site or in the project house.

Historical background

The Buddhist temple II [3] is located in Krasnaya Rechka, an archaeological site of the upper Chuy valley between Bishkek and the Issik Kul lake which flourished from the 6th to the 12th centuries AD (Fig. 1). The city of Krasnaya Rechka was discovered by archaeologist Alexander Natanovich Bernstam who carried out the first research there in 1938 [4]. The site is formed by two elevated inner cities (*shakhristan* 1 and 2) that include the administrative quarters (Fig. 2), whilst outside the city walls are the residential buildings and an area known as the necropolis. The cities of the Chuy valley were characterised by a cosmopolitan community and this is confirmed by the archaeological investigation that produced religious artifacts belonging not only to Buddhism but also to other religions such as Nestorian, Islamic, and Zoroastrian.

The Buddhist temple II is significant for the study of development of Buddhism in Central Asia before the arrival of Islam. It is not the sole Buddhist temple in the Chuy valley, but it is the only one surviving above ground, showing the spread of Buddhism from Bactria and Gandahara towards China. The temple was described as a crossroad of Gandhara, Tokhrastian, Eastern Turkestan and Central Asian styles [5]. The cella is square in plan with interior dimensions of 6x6m, and is surrounded on three sides by a corridor (Figs. 3-4). It was dated as belonging to the second part of the 7th century AD, but recent investigation with radiocarbon dating showed that the outer wall dates to about 980 AD [6]. The ambulatory walls formed a courtyard in the area opposite the cella (east), measuring 11.3x10m [7]. In 1961 part of a reclining, 8m.-long Buddha (Fig. 5) was excavated in the west corridor [8]. This was found resting on a *suffah*, a pedestal made of mud brick (measuring 43-45x22-24x8-10cm and bedded with the stretcher side) that was used for constructing the borders of the *suffah*, and a conglomerate of soil and broken mud brick as infill. Archaeological investigation showed that the height of the *suffah* was 1m and its width was 1.7m [10]. At the time of excavation (1961) the Buddha sculpture could not be conserved in Central Asia because of lack of expertise. It was therefore cut out and sent to the Hermitage Museum, Saint Petersburg. An inspection in 2004 showed that only one small fragment had been treated, the remaining portions being still in their original packing after more than forty years.

The excavations revealed also that the corridor and cella were characterised by a mud floor. The temple was built with mud brick, and the walls (originally from 2 to 3 metres in thickness) were coated with a mud plaster of 5mm thickness. The excavation of the southern corridor revealed several fragments of wall paintings depicting the life of the Buddha. The predominant colours used in the paintings were blue and black; other pigments were yellow-orange, red-crimson, and green [11]. Wall paintings were applied over a 2-3mm coat made of gypsum. Another important constructional aspect is that the temple is built on a massive mud brick platform, a typical system adopted in several Central Asian sites, and that no trace of a stupa was found. The roofing method is not clear as archaeologists have contradictory views [12].
In September 2003 a temporary shelter coat was applied to the most endangered parts of the temple so as to protect the mud brick walls from further erosion (Figs. 6-9). The shelter coat was applied as follows [13]:

- geotextile (Dupont Typar Style SF 32) was employed as a separation layer between the historic structures and the shelter coat;
- construction of a mud brick shelter coat. The mud bricks employed for the construction of the encapsulation are clearly legible as a modern intervention. Mud brick buttresses were built in the south corridor;
- filling of gap between the geotextile and mud brick skin by employing dry sand;
- plastering of the mud brick shelter coat with a mix of soil and straw.

In May 2004 the following decay symptoms were noticed:

- lack of growth of vegetation on the shelter coat, whilst the exposed parts of historic walls were overgrown;
- man-made decay. On several occasions neighbouring farmers were found riding their horses on the temple structures and the result was that the top part of some of the shelter coats had collapsed;
- fair coving effect in the elevations facing the cella.

The shelter coat proved to be an excellent medium to prevent further decay of the earthen structures, being sacrificial towards the historic fabric. A study of damage of the structures was done, in similar fashion to that done in the Otrar project, with the help of drawing conventions in both English and Russian [14].

The next section, describes the experimental analysis of the soil used as building material for the Buddhist temple and of the repair material to be employed in the future.
The construction of a protective shelter structure was envisioned from the very beginning of the project. It was built in Autumn 2006, but a more detailed explanation of its design and construction is beyond the scope of this article.

LABORATORY ANALYSIS

Aim and objectives of the work

The aim of the testing was to evaluate the use of soil as a repair material for the future conservation of the Buddhist temple II. Since the present shelter coat is only a temporary protection measure, it was necessary to test the repair material to be employed in the final conservation of the temple. It is planned in fact to repeat the application of the shelter coat, but with materials with improved performance. The fact that the repair material will be used also for inserting in the historic fabric (structural consolidation of eroded parts, limited reconstruction) shows the need to assess its behaviour in terms of sacrificiality. Testing was done in the project house laboratory. Several samples of possible repair materials were taken from different quarries, but only the best performing one is considered here (named K, from near the village Kenesh [15]).
Training in conservation and laboratory work was a continuous and daily task (Fig. 10). This was carried out in terms of formal lectures and practical sessions on empirical testing and analysis in the project house laboratory. National experts took part in the session and every participant was provided with datasheets on which to take notes of results. Comparative analysis between samples was undertaken and comments were made by the trainees on the main achievements of such tests. The work explained in the following pages was undertaken entirely in the project house field laboratory with the help of four Kyrgyz trainees (2 architects, 1 engineer, and 1 conservation chemist) who carried out most of the analysis under the supervision of the author. The link with the Kyrgyz State University of Construction, Architecture, and Transport was continuous throughout the project. Their input was especially useful when designing the test walls mixes.

Characterization tests [16]

Sampling

Sampling of earthen material from the walls of the Buddhist temple was documented with two photographic records showing an overview of the structure under study and a detailed close up with the name of the sample and a scale. Sample location was also marked on the plan of the temple. During the sampling procedure notes were taken after visual analysis and this information proved to be an important reference for future study. The 21 historic samples were collected by choosing typical, extreme, and marginal cases. I refer to the totality of the 21 historic samples as the atlas. Sample K was considered as repair material and the result of its assessment is provided here. A comparison is made for every test between sample K and the 21 historic samples.

Soil colour

The aim of this investigation is the determination of the colour of air-dried soil samples. Soil colour was measured by comparing the colour of the dry samples with the revised edition of the *Munsell® Soil Colour Chart* under west light, late morning. Following this standard method, samples were classified according to their colour characteristics.
All samples are characterised by the notation YR that stands for yellow-red, and by the preceding numerical range (value notation) 10. The only element that was found to be different in several specimens was the value/chroma notation. Samples were found to have a value notation varying between five and seven and by a chroma notation varying between two and four. This particular combination of notations can be visualised as a compact area of the 10YR sheet of the *Munsell® Soil Colour Chart*. This even distribution of colours denotes a strong homogeneity of the analysed samples, and of the structure under examination. This is certainly to be related to the fact that the soil used for the construction of the temple was quarried

locally and this explains the similarity of colours. The colour of sample K (pale brown, 10 YR 6/3) matches extremely well that of the historic samples of the Buddhist temple II.

Soluble salts content

Soluble salts analysis was carried out on every sample by separating the water in which the soil was left to sediment. The solution of water was then left to evaporate. This standard procedure was repeated three times and salts were found in an average concentration of 2.8%. The majority of the analysed population shows a moderate salinity and this is also true for the repair material K which is the one that shows the lower content of soluble salts (1.6%).

Carbonates content

The aim of this test is the determination of the percentage of carbonates in the mineralogical composition of the soil samples [17]. The carbonates content of soil was determined by crushing the samples, followed by oven-drying, weighing and dissolving into a solution of hydrochloric acid. After complete dissolution was accomplished, samples were filtered, oven-dried until no further weight change.

Carbonates were found in all of the tested samples and the average value is 15.22%. This value is extremely close to that of the repair material K (14.4%). The conjecture is that the predominant acid-soluble element of the tested samples is mostly calcium carbonate, but this is not supported by experimental analysis.

Measurement of pH

The aim of this experiment is the determination of the pH level of soil samples in their wet state. Research on the relationship between the pH level and the behaviour of soil as a building material is not yet complete, but it is certain that durability is affected by it. Some discussion on wet clays is given by Clifton and Wencil Brown who point out that the behaviour of clay particles when wet is largely controlled by the exchangeable cations of the clay and the pH of the clay-water system. For example, a low pH promotes flocculation of the clay particles from suspension, while a high pH can lead to the formation of a stable suspension or dispersion of clay particles [18].

The pH of soil samples was measured through the procedure outlined by Clifton and Wencil Brown [19]. The soil was sieved with the 0.42 mm sieve and a sample of 20.0 gr of passing material was oven-dried at 100 degrees C for 24 hours. Then after weighing, the sample was added to 40 ml of distilled water and mixed with a glass rod. After one hour of standing, a pH metre was used to take readings. The pH metre used for this test was a pocket-sized instrument (pHep 3) ranging from 0.0 to 14.0 pH, with a resolution of 0.1 pH, and an accuracy of 0.1 pH.

The definitions of pH according to the reaction of soils are: acid (pH<5.6), mildly acid (5.6<pH<6.5), neutral (6.6<pH<7.3), mildly alkaline (7.4<pH<7.8), alkaline (pH>7.8). The comparison of this classification with the data obtained shows that the average pH value of the selected population of samples (11) is alkaline. The trend shown here is that only one sample (B2-6) out of 11 is mildly alkaline, whilst the remaining ten have alkaline reaction. It can therefore be speculated that the influence of the calculated pH levels on the decay of earthen material is, generally speaking, minimal, at least within the range of the considered population (pH of sample K is 8.6). To conclude, the main finding of this experiment was: the pH does not seem to influence negatively the overall performance of the historic samples, and this is also true for the spoil heap samples.

Particle size distribution

The scope of this test is the calculation of the range of particle sizes of the samples, together with the determination of their particle size distribution curve. The methods used for the determination of the particle size distribution were two: sieving for the coarser material (gravel and sand), and sedimentometry for the fines (silt and clay). This technique is universally accepted by several textbooks on soil analysis. It should be mentioned that international limits were adopted in the analysis of soil: gravel (particles with diameter bigger than 2000 micron), sand (particles with diameter between 2000 and 20 micron), silt (particles with diameter between 20 and 2 micron), clay (particles with diameter smaller than 2 micron).

The first relevant finding of this analysis is given by the average percent values for the 21 samples collected in the Buddhist temple II (Fig 11): gravel 0.2%, sand 63.4%, silt 29.0%, clay 7.4%. Such values confirm the

trend of recent research on the influence of clays in the manufacturing of earthen building materials, which is that the best soils are those that contain hardly any clay. Another important finding was identified by classifying the soil samples according to the fraction prevailing in their composition (gravel, sand, silt, or clay). The results show that in all cases the prevailing fraction was found to be sand.
Another major finding derives from the study of the granulometry curves of the samples (Fig. 12). All curves were grouped together in order to define a reference area for the Buddhist temple II samples. The maximum curve was calculated, together with the minimum curve. They demarcate an area that can be considered as a grading envelope or reference zone.
The recommended zone, being the product of the analysis of a limited number of 21 samples, is approximate and not rigid. It is in fact possible that soils which do not behave within the parameters of the zone are actually satisfactory in practice. The usefulness of a recommended zone derives from the fact that those soils which comply with it are more likely to behave satisfactorily than those which do not. The employment of this guidance zone is of great use especially for comparing it with the granulometry curves of the repair materials. Sample K (Fig. 13) shows a high proximity to the average curve and this proved to be a well performing sample in terms of granulometry curve.
Roundness of grains (low and high sphericity) and colour of sand grains was studied after sieving by visually analysing the samples with a magnifying lens. The studied soil samples being of alluvial origin, the most widespread components are quartz, feldspar, and other rock fragments. Following such procedures, samples were classified according to the table provided by Adams and MacKenzie [20]. Analysis of the mineralogical composition of both historic and repair material was carried out at the Construction Department, Faculty of Engineering, University of Bishkek [21].

Atterberg limits (plastic limit, liquid limit, and plasticity index)

The aim of these tests is the determination of the rheological behaviour of soils in their wet state. Before experiments were carried out, samples were crushed with a rubble pestle and then passed through a 4 mm sieve. A hand-operated Casagrande apparatus and grooving tool were employed for the determination of the liquid limit (Fig 14). The liquid limit device is used to evaluate the relationship between the moisture percentage of soil and the number of blows required to close a groove made into the soil sample. It determines when a soil turns from a plastic to a liquid state.
The plasticity index gives useful indications about the behaviour of wet soils and these characteristics can be qualified through the diagrams of the Atterberg limits such as those for cohesion, activity, and expansion. To conclude, the main category of results of these tests were: the strength of soils (the lighter the index, the higher the clay content and the stronger the soils), the definition of soils (in terms of their activity, cohesion, and expansion), and the behaviour of soils in their wet (expansion) or dry (shrinkage) state.

Physical tests [22]

Preparation of samples

Soil prisms (measuring 5x5x1 cm) were manufactured in order to test their behaviour against erosion, wetting and drying, and abrasion (Fig. 15). They were cast from a timber mould and subjected to physical tests. The overall number of manufactured prisms was 53 for the historic samples and 33 for the repair material. Because different soils show different workability when mixed with the same amount of water, and because different samples show a different optimum water content for maximum performance, the mix for molding the specimens was carried out by adding the amount of water necessary to reach a state between the plastic limit and the liquid limit of every soil sample. Some samples attained their workability when their plastic limit was reached, whilst some others needed more water. As a consequence, workability was defined as the level of water that would allow the mix to be packed in the corners and edges of the mould with the help of a spatula. Then specimens were put to dry at room temperature on evaporating dishes, and turned on their sides after one day.
I refer to the totality of the historic samples as the *atlas*. The list of physical tests is: erosion, wetting and drying, shrinkage, abrasion, freeze and thaw.

Erosion test (drop test)
The aim of the erosion test, also known as drop test or perforation test, is the understanding of the behaviour of soil prisms when submitted to physical abrasion and fluid erosion, both occurring naturally due to heavy rain. Erosion is understood as the result of an accumulation of mechanical energy which is directly proportional to the intensity and height of drops (Fig. 16).
The aim of the experimental design was to create a controlled artificial rain with the scope of eliminating two main variables: intensity of drops and height of source of drops. This type of weathering simulation is an important test in conservation terms because it gives an indication of the behaviour of mud brick when exposed to the repeated impact of drops of rain. However, the ideal system which simulates rain is certainly more aggressive than the naturally occurring causes of erosion. It does not need a sophisticated apparatus, but it was found to be an effective method for the testing of soil prisms. It should be noted here that the experiment was designed to force the drop to impact perpendicularly the horizontal surface of the sample. This is a realistic situation in archaeological structures because their horizontal earthen surfaces are often not protected by overhanging eaves or by other architectural elements. Samples were put to rest on a timber railing and a key burette with a straight stopcock was used to produce one drop of distilled water per second. This simulated rain was dropped from a height of one metre from the smooth surface of the samples. Measuring the diameters of the holes was found to be a complicated task because the cavity was often not well defined, and therefore this data was not recorded.
The results in Fig. 17 give an idea of the final perforation time of every sample. Some samples were quickly perforated, whilst others needed more time. The average perforation time for all historic samples is 12:41 minutes, and the comparison with sample K (12:57 minutes) shows that the latter is equally resistant to erosion. The results on Fig. 17 show that the perforation time of the samples was variable. Samples were classified according to their complete perforation time:

- very slow (>20 min). No samples;
- slow (15-20 min). Samples B2-7, 17, 18;
- medium (10-15 min). Samples B2-2, 5, 6, 9, 12, 13, 14, 15, 20, 21;
- fast (5-10 min). Samples B2-1;
- very fast (0-5 min). No samples.

Wetting and drying test
The scope of this test is the determination of the behaviour of soil prisms when subjected to wetting and drying cycles (Fig. 18). The experimental design is again a more aggressive simulation than the naturally-occurring causes of weathering of mud brick. In this respect the test is not a precise repetition of the field conditions of earthen buildings where the process occurs more slowly. Wetting and drying cycles have been recognised as an important factor in mud brick as well as in stone deterioration. The same mechanisms are at work in mud brick, but probably to a much greater extent. The results of the wetting and drying actions are most dramatic during drying conditions when the most significant amount of surface material becomes friable and falls from the walls at the slightest touch. The actual stresses resulting from wetting and drying cycles, as well as other internal forces, are certainly more obvious on the exposed surface of the mud brick material. For most practical purposes, when not in the presence of excessive moisture, the deterioration caused by such factors as wetting and drying cycles are limited to the surface or to the material near the surface.
In order to facilitate their manipulation, samples were positioned horizontally onto a stone slab. Then they were totally immersed in ambient-temperature tap water for one minute, after which they were dried at room temperature. After drying, samples were removed from the slab and weighed. This completed one cycle of the test. For these samples the problem was at first what to consider as prism and what to consider as loss material. The method used here consisted in considering as prism the material included in the 5x5 cm perimeter. The calculation of the data was carried out in the following way: after the failed prism was dry-weighed, the resulting figure was subtracted from that of the dry weight of the prism before the cycle of wetting and drying was started. The resulting number was the weight loss of the soil prisms after the first cycle.
It was decided that because some samples nearly failed completely, the test would be interrupted after the fifth cycle. As this was such an aggressive test, further repetition would have only caused further and

unquantifiable disintegration of the samples. The employment of several cycles is a standard procedure for the testing of more durable earthen material such as that stabilised with cement, acrylic, or lime. In the case of unstabilised soil samples the continuation of the test to more cycles is not easily applicable. Another reason for not undertaking more cycles is related to the comparative nature of the methodology employed in this analysis. It was felt that useful data would be secured anyway if the samples underwent just five cycles.

The results of the wetting and drying test are gathered together on Fig. 17. Prior to the description of the extent of the decay, it is important to define some parameters:

- very large failure, with weight loss from 100% to 80% (no samples);
- large failure, with weight loss from 80% to 60% (sample B2-12);
- medium failure, with weight loss from 60% to 40% (samples B2-10, 15);
- slight failure, with weight loss from 40% to 20% (samples B2-2, 5, 11, 13, 14, 21);
- very slight failure, with weight loss from 20% to 0% (samples B2-6, 7, 8, 9, 17, 18, 19, 20).

This classification of samples according to their weight loss is a reliable method for measuring their performance and the percent expression is the only means of comparing the results.

Abrasion test

The aim of this test is the study of the behaviour of soil prisms to mechanical abrasion and wear and tear. Abrasion is an important issue in conservation terms as it can be caused by a combination of wind and sand, by animals rubbing themselves on the bare wall, or it can also be accidentally caused by man.

The device used for this test consisted of a pallet weighing one kilogram and characterised by two retaining strips with the function of avoiding sliding of the sample. General purpose sand paper with the following characteristics was employed: coarse, grade S2 (**Cabinet Sandpaper)**, dimension of strips 28x8 cm. Abrasion was conducted on the smooth face of the sample (top face), and one new sheet of sandpaper was used for every sample.

A single back and forth motion constituted one cycle, and fifty cycles for every sample were felt to be representative of the mechanical abrasion test. In order to attain results that are independent of the shape and the size of the sample, the dry weight of abraded material was recorded per square centimetre of the abraded area. The formula used for this calculation is: coefficient of abrasion = (weight of abraded material)/(abraded area). The coefficient of abrasion was calculated for every sample and expressed in gr/cm^2.

The results in Fig. 17 do not show any correlation between the coefficient of abrasion and the clay content of every soil sample. The coefficient of abrasion of samples varied from 00.9 to 0.24. The main finding of this test was: the coefficient of abrasion of soil prisms does not seem to be a function of the amount of clay in the mix.

Freeze and thaw test

This is an important test as the annual temperature in Krasnaya Rechka often falls below zero with lows of -20 degrees C. The soil prisms were dry-weighed and put to rest on a tray over a cloth saturated with water. Then they were immediately put into a refrigerator for 24 hours at a temperature of -5 degrees C. The tray was then put to thaw at room temperature for 24 hours. This test was repeated for 10 cycles after which the samples were dried at room temperature.

Monitoring of decay of samples was undertaken after the third cycle because decay started to be visible only then. Decay was described with a standard system: very little decay, little decay, moderate decay, serious decay, and very serious decay. Results are: very little decay (B2-19), little decay (B2-9, B2-8), moderate decay (B2-5), serious decay (no samples), very serious decay (B2-1, B2-2, B2-6, B2-14, B2-11, B2-12). As for the behaviour of samples K, it was noticed that after the 10^{th} cycle the decay was already much higher than that of any historic sample.

Shrinkage test

The aim of this test is to study the behaviour of loam samples with regard to shrinkage, and this has important implications in conservation terms.

Shrinkage was calculated by employing a half-cylindrical mould measuring 14.0 cm in length and 2.6 cm in diameter. The amount of water added to the soil was that which was necessary to reach a state between the plastic limit and the liquid limit of every soil sample. The main finding of this test was: the shrinkage of soil samples is, for the majority of cases, directly proportional to the amount of clay in their mix. The average value for the historic samples is 3.2%, whilst the shrinkage of sample K is 2.9%.

Conclusion from results and discussion

This section examines and evaluates the proposed use of sample K as repair material for the Buddhist temple II by comparing the experimental results. Sample K was first selected as a result of consulting local craftsmen who suggested this as one of the best soils for mud brick making in the area around the Buddhist temple. As was explained in previous sections, the analysis of sample K was carried out by precisely repeating the set of experiments undertaken on the historic samples. This was necessary not only for correlating any repair with historic materials, but also for allowing comparison of these with the results of the atlas samples.

The hypothesis is that the assessment of the loam for the repair of the Buddhist temple II can be made using a simple methodology. The main idea behind the assessment of the repair material is that its performance is considered positive if it behaves sacrificially towards the historic brick.

The first important point provided by the analysis of soil samples derives from the visual comparison of the colour of the repair material with the colour of the historic mud brick. The match is extremely close and this was also confirmed by the author’s direct observation. Furthermore, experimental analysis provided several other significant findings.

The study of grain size analysis reveals that the clay content of sample K (10.7%) is higher than that of the average value of the 21 samples (7.4%), whilst the comparison of silt contents is reversed (21.4% sample K, 29.0% average value of the atlas samples). Sand (67.8% sample K, 63.4% average value of the atlas samples) and gravel (0.1% sample K, 0.2% atlas samples) have more similar values. This might again have positive implications in philosophical and durability terms as the replacement soil might behave slightly as sacrificial towards the historic one.

As for pH, the analysis shows that it does not have negative implications in terms of sacrificiality of the historic fabric towards sample K.

Carbonates content of sample K (14.4%) is very close to that of the average of historic samples of the Buddhist temple II (15.22%), showing good compatibility between the samples. This is also true for the salts content that is much lower for sample K (1.6%) than that of the historic samples (2.8%).

The plasticity index influences the performance of soil in conservation terms: higher plasticity indices are accompanied by larger expansions upon wetting and larger shrinkage upon drying. Sample K is characterised by a plasticity index of 0.4. This means that the soil might expand between 4 and 10% [23]. But this also means that the repair material will expand much less than the historic ones (average value for plasticity index of the historic samples is 8.3). It seems that their dimensional responses to moisture, and therefore their durability, are not close.

The response of the sample to physical tests will be explained here schematically:

- Erosion test. The perforation time of sample K (12:57) was the same as that of the average value for the 21 historic samples (12:57);
- Wetting and drying. The percentage of lost material of sample K (25.5%) was less than that of the average value for the historic samples (27.5%);
- Shrinkage. Sample K (2.9%) showed a lower shrinkage than that of the historic samples (3.2%);
- Abrasion. Sample K (coefficient of abrasion 0.19 gr/cm^2) behaved sacrificially towards the average value of the historic samples (0.15 gr/cm^2).
- Freeze and thaw. The sacrificiality of sample K was apparent after concluding the eight cycles, whilst historic samples showed a similar decay after the 10th cycle.

These findings are extremely significant as physical tests show that the tendency is for the repair material to behave sacrificially towards the historic material. To recapitulate all the results, of the eleven tests that were carried out on the repair material K, nine proved that K would behave sacrificially towards the historic fabric (only the Atterberg limits and wetting and drying tests proved the opposite). The practical implication is that its employment for the conservation of the Buddhist temple II would be positive. The conclusion after this analysis is that sample K can be used for inserting in the fabric of the temple, having confirmed that sample K behaves sacrificially towards the historic brick.

TEST WALL CONSTRUCTION AND MONITORING

Aim and objectives of the work

The Test Wall project follows the philosophical principle that testing of conservation materials should not be carried out directly on archaeological fabric [24]. Test wall construction was dictated by the need to study the best-performing material for the conservation of the Buddhist temple II, especially for plastering [25].

In October 2004 six test walls were built in the yard of the project house (in Krasnaya Rechka village), whose distance from the Buddhist temple is of 3354 m [26]. The site was cleared of all vegetation, after which it was made flat. Trenches were excavated so as to host the walls. Geotextile (Dupont™ Typar® Style SF 32) was employed as a separation layer between the virgin soil and the first course of mud brick (Fig. 19). The depth of the trench was such as to hold two courses of mud brick (20 cm). After the first two courses were built, the gap between the trench and the wall was filled with rammed soil.

Six test walls (Fig. 20) were aligned on the north-south axis so as to have their four sides exposed to the cardinal points. Test walls measured circa 1.50x1.20x0.50m (height, width, depth). They were constructed with mud bricks measuring 43x22x8cm and with mud mortar (90% soil K + 10% sand):

- TW 1: mud brick wall (by volume: 90% soil K + 10% sand) without plaster. Soft capping was made of a bed of local grass that grows in the vicinity of the Buddhist temple II (circa 100 m). The bed was cut to a thickness of 8 cm and curved during construction. Humus was employed for the purpose and a separation layer of geotextile was inserted between the mud brick and the capping.
- TW 2: mud brick wall (by volume: 80% soil K + 10% sand + 10% chopped wheat straw) without plaster. Length of straw: 3-8 cm. Soft capping as in TW1.
- TW 3: mud brick wall (by volume: 80% soil K + 10% sand + 10% wheat straw) with mud scratch coat (80% soil K, 10% sand, 10% chopped wheat straw), and a skim coat made of the same proportions, but with 5% lime putty added. An extra skim coat was applied and the proportions are: 65% sand, 5% lime putty, and 30% soil K. Lime was sieved with a 2 mm sieve. Capping made with the same mixes. Thickness of coats: 1.3 cm (first), 1 cm (second), and 0.5 cm (third).
- TW 4: mud brick wall (by volume: 80% soil K + 10% sand + 10% wheat straw) with mud scratch coat (80% soil K, 10% sand, 10% chopped wheat straw), and skim coat made with 3% straw, 5% lime putty and 10% sand, the rest soil K. Capping made with the same mixes. Thickness of coats: 1.3 cm (first) and 1 cm (second).
- TW 5: mud brick wall (by volume: 80% soil K + 10% sand + 10% wheat straw) with mud scratch coat (80% soil K, 10% sand, 10% chopped wheat straw), and skim coat made with 3% straw, 10% lime putty and 10% sand, the rest soil K. Capping made with the same mixes. Thickness of coats: 1.3 cm (first) and 1 cm (second).
- TW 6: mud brick wall (by volume: 80% soil K + 10% sand + 10% wheat straw) with unamended mud plaster and capping. Composition of both plaster and capping (by volume): 80% soil K + 10% sand + 10% chopped wheat straw. Plaster was applied in one layer. Length of straw: 3-5 cm. Geotextile was employed as a separation layer between the mud brick and the capping. The thickness of the coat was 1.3 cm.

After completion of the test wall construction, both horizontal and vertical joints of TW 1 and TW 2 were pointed. The test walls to which plaster was applied were not pointed so as to allow proper keying of the coat to the fabric [27]. In September 2005, three new test walls were built in the project house yard (Fig. 21). The methodology employed for these followed that used for those constructed in October 2004 (as described in the previous section). The three test walls were provided with a permanent shelter structure made of timber and plastic sheets, so as to replicate conditions under a shelter structure. The main reason for this experimental work was to test the influence of the following decay mechanisms on three different plaster mixes: capillarity rise and soluble salts attack, erosion caused by wind-blown sand or silt, freeze-thaw cycles, wetting-drying cycles. The best-performing plaster will be employed for the conservation of the Buddhist temple II. The sheltered walls of the experiment are to help demonstrate the efficacy of the shelter, but also to select the most adequate plastering material for the shelter coat that will be rebuilt as part of the conservation programme. It should be noted here that assessment of the decay of the three sheltered walls cannot be reported here since their construction was undertaken one year later than the exposed test walls.

Monitoring

Monitoring of wall decay was designed so that the following parameters could be recorded: colour change, erosion, cross-section documentation, coving, photographic documentation, extent of cracks, and weather. The data was to be recorded after 3, 6, 12, and 24 months from the construction date of walls:

- Colour change. The assessment of colour change will be undertaken with the revised edition of the Munsell® Soil Colour Chart.
- Erosion. Qualitative assessment of erosion was carried out by employing the following indices: (3) little erosion, (2) moderate erosion, (1) serious erosion.
- Monitoring of cross sections. Cross-sections are useful for monitoring erosion, including coving effect, and this was measured by the documentation team.
- Photographic documentation. Both digital and analogue photographs are taken at regular intervals from the same distance back from the centre of each wall. Photographs were taken soon after construction of the test walls, and also after 3 months, 6 months, 12 months, and 24 months from the construction of the walls.
- Weather. Weather is constantly monitored (precipitation, temperature, and relative humidity). Measurements are carried out with a portable weather station and frequency of measurements vary according to availability of staff, generally monthly in the winter period when staff is less available in the site.

Assessment of decay after two years from construction

In all cases the most serious erosion is found at the base of the wall. Capping of Test Walls 3-6 is behaving extremely well, whilst the turf capping of the first two walls failed due to lack of moisture. Coving is generally deeper on the south face of the wall and this is due to the fact that the rate of decay due to crystallization is influenced by directional exposure to the prevailing wind and sunshine. This is of course more noticeable in the elevations facing south and east, where the conditions for the salts to remain in solution change more rapidly. All test walls show the following general tendency: west elevations are behaving better than east elevations. The plaster of the upper parts of west elevations is still adhering and shows very little erosion. The plaster of the upper parts of east elevations shows deep erosional patterns. So far no major difference is noticed between the decay of south and north elevations: only at the footing level is the south elevation decaying faster.

Test Wall 3 shows only small portions of the skim coat still in place on the north façade, in the capping, and on the west façade (the skim coat of the south façade collapsed completely).

The Test Walls exercise proved to be extremely useful and the information gathered provided us with the following main results:

- The main decay mechanism is represented by rising damp. All walls were purposely constructed without any footing or foundation so as to accelerate the phenomenon. It is therefore suggested that before erecting any wall in the B2, it is essential to provide proper foundations made of two or three courses of fired brick (in all cases cement is to be avoided).
- Capping proved to be effective for Test Walls 3-6, walls from 3 to 5 being the best performing.
- As for the plastering material, qualitative assessment of decay was conducted by the author and the comparison between Test Walls 3, 4, 5, and 6 shows that Test Wall 5 is the best performing in terms of erosion.

CONCLUSION

This study aimed to demonstrate the feasibility of using a field laboratory to assess repair materials for the conservation of earthen archaeological sites. There is at present no standardized protocol to follow in order to understand whether a soil (mud brick, rammed earth, or other) will behave sacrificially if inserted in the historic fabric. As this research progressed, it became clear that there is now a need to test the applicability of the methods explained here in a variety of sites, initially in Kyrgyzstan and then further afield in Central Asia (and in this sense monitoring plays a relevant role). Clearly there is much work yet to be done, but this study has provided an invaluable beginning from which such future research can proceed.

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Fig. 1. The site of Krasnaya Rechka as part of the upper stretch of the Silk Roads.

Fig 2. Aerial view of Krasnaya Rechka showing the two *shakhristan* (inner city) and the location of the Buddhist temple II (white circle). Picture kindly provided by Renato Sala

Fig. 3. Aerial picture of the Buddhist temple II (picture kindly provided by Renato Sala). Only the south and east corridor walls survive because extensive soil quarrying was carried out before 1938, date of the first arcaheological excavation

Fig. 4. The cella of the Buddhist temple II before conservation (2002). The arch on the left is the result of illegal quarrying. The site was found eroding at high speed due to rainy weather conditions in the area. Picture: Valery Kolchenko

Fig. 5. Reclining Buddha, earth sculpture, Buddhist temple II, Krasnaya Rechka. Both sculpture and pedestal were painted red. Archival picture, 1961

Fig. 6. Buddhist temple II, Krasnaya Rechka: the ambulatory passage before emergency shelter coating, 2002. Picture: John Hurd

Fig. 7. Buddhist temple II, Krasnaya Rechka: the ambulatory passage after emergency shelter coating, May 2004. Shelter coating of wall on the right hand side is explained in Fig 9.

Fig. 8. Shelter coat construction showing mud bricls, sand infill, and geotextile (2003). Picture: Jumamadel Imankulov

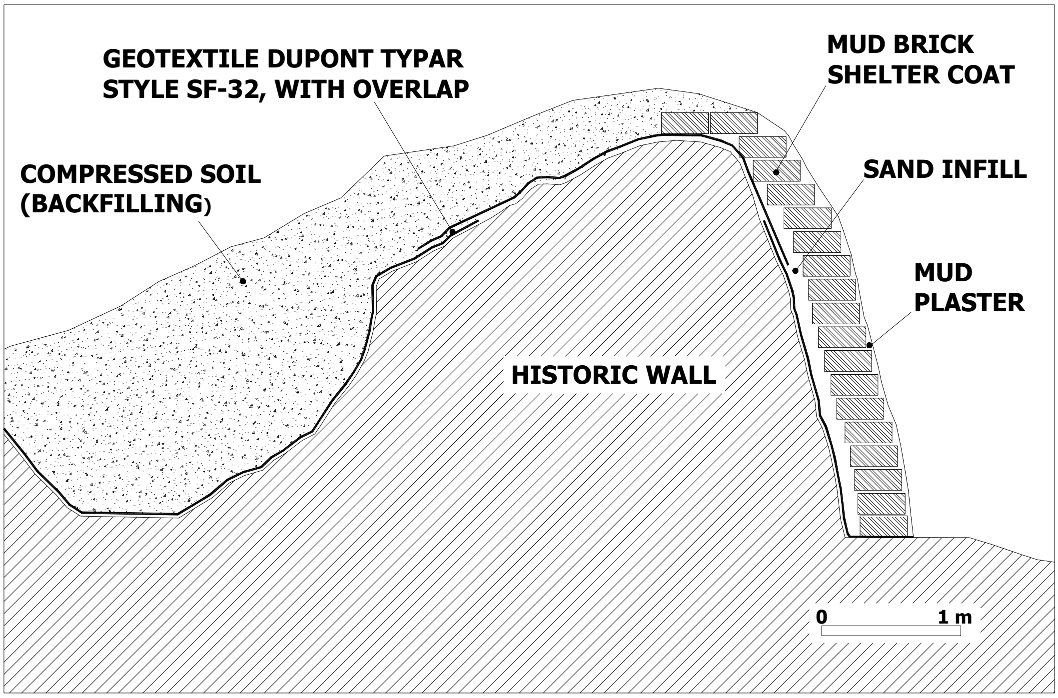

Fig. 9. Drawing explaining shelter coating process (extent of historic wall is not defined). The portion on the left was backfilled as a conservation measure.

Fig. 10. Training session on soil analysis in the project house laboratory (2004), Krasnaya Rechka

Fig. 11. Particle size distribution of the Buddhist temple II samples. The latter two lines show comparison between average values for the 21 historic samples and the possible repair material K.

Sample name	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
B2-1	4.9	32.6	62.3	0.2
B2-2	13.2	22.7	63.6	0.5
B2-3	6.2	31.4	62.3	0.1
B2-4	11.2	25.1	63.2	0.5
B2-5	5.6	32.6	61.6	0.2
B2-6	9.7	31.2	58.9	0.2
B2-7	12.0	24.5	63.4	0.1
B2-8	3.2	32.3	64.4	0.1
B2-9	3.3	28.5	68.2	0
B2-10	11.8	23.5	64.5	0.2
B2-11	3.5	33.3	63.0	0.2
B2-12	6.0	33.1	60.9	0
B2-13	3.3	33.0	63.7	0
B2-14	12.0	26.4	61.5	0.1
B2-15	12.4	27.9	59.5	0.2
B2-16	5.6	28.4	65.5	0.5
B2-17	5.8	34.7	59.4	0.1
B2-18	5.8	23.6	70.4	0.2
B2-19	3.3	26.1	70.5	0.1
B2-20	4.6	31.0	64.3	0.1
B2-21	13.2	26.1	60.5	0.2
Average	**7.4**	**29.0**	**63.4**	**0.2**
K	10.7	21.4	67.8	0.1

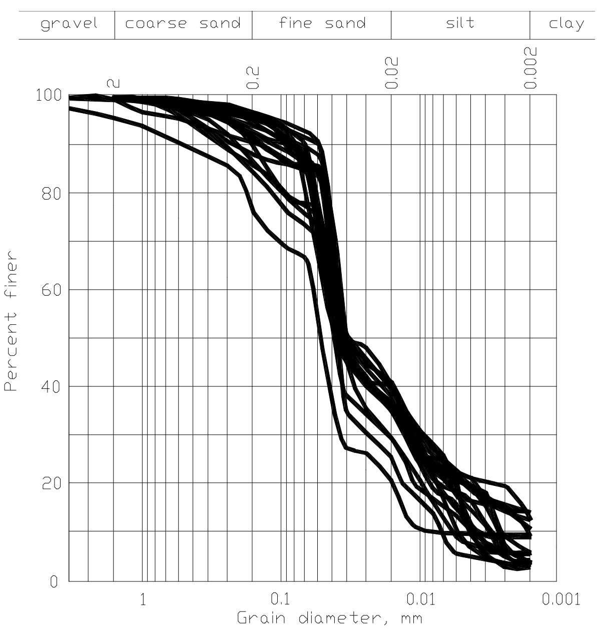

Fig. 12. Diagramme showing grouping of granulometry curves of 21 samples of historic mud brick (Buddhist temple II)

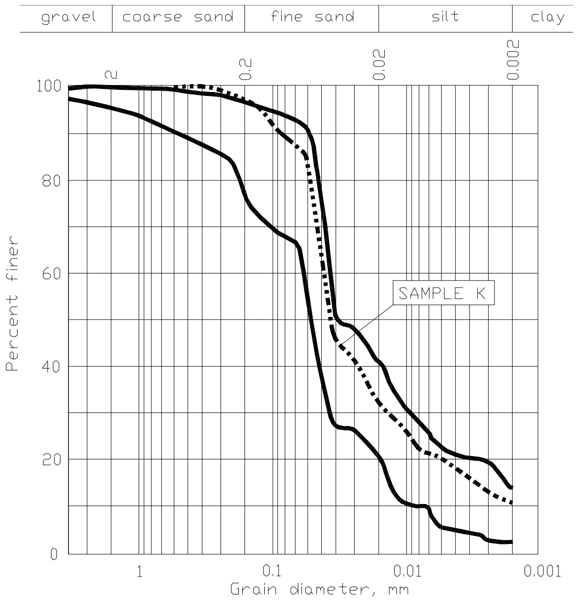

Fig. 13. Diagramme showing grading envelope calculated on 21 samples of historic mud bricks (see Fig. 12). The dotted line is the granulometry curve of sample K (possible repair material). Comparison shows compatibility between repair and historic material

Fig. 14. The Atterberg limits determine the rheological behaviour of soils in their wet state

Sample name	**Liquid limit**	**Plastic limit**	**Plasticity index**
B2-1	21.9	14.8	7.1
B2-2	18.6	15.2	3.4
B2-3	27.1	16.5	10.6
B2-4	21.7	18.7	3.0
B2-5	22.9	21.9	1.0
B2-6	19.1	15.3	24.8
B2-7	22.6	18.5	4.1
B2-8	21.2	13.6	7.6
B2-9	26.1	19.1	7.0
B2-10	19.6	13.8	5.8
B2-11	21.9	19.1	2.8
B2-12	17.8	NA	NA
B2-13	20.5	18.6	1.9
B2-14	54.0	23.4	30.6
B2-15	22.0	16.2	5.8
B2-16	19.6	NA	NA
B2-17	32.9	17.7	7.6
B2-18	21.7	6.5	15.2
B2-19	21.8	18.6	3.2
B2-20	30.2	22.5	7.7
B2-21	25.3	22.0	3.3
Average	**24.21**	**17.5**	**8.03**
K	18.3	17.9	0.4

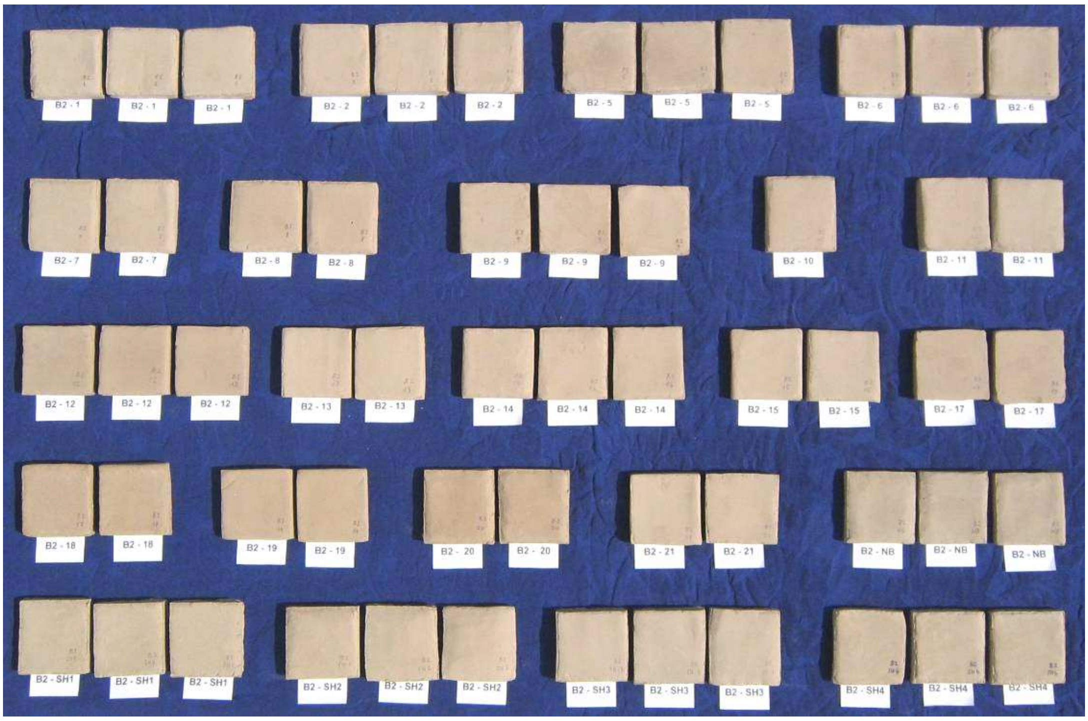

Fig. 15. Preparation of samples before physical testing. Represented here is a portion of the samples that were moulded for testing.

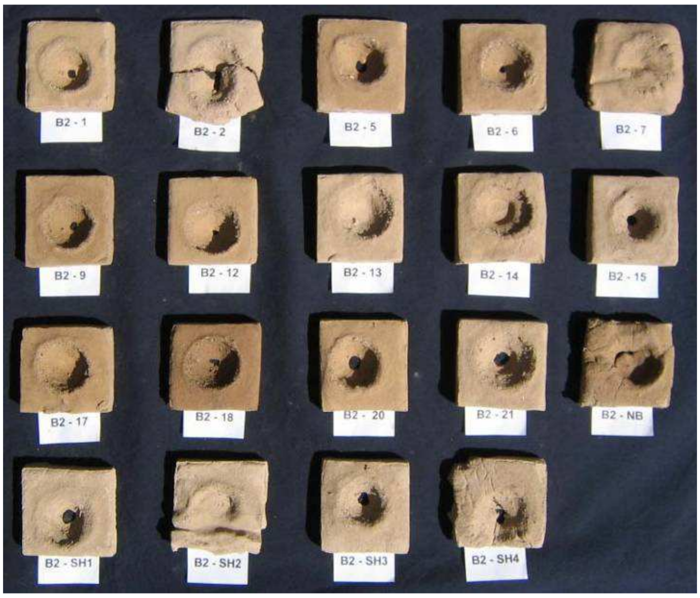

Fig. 16. Buddhist temple II. Results after drop test

Fig. 17. Results after drop test, wetting and drying, and abrasion test. Not all samples were subjected to physical testing due to the size of material taken from the historic fabric. This was done in such a way to limit destruction of earthen walls

Sample name	Drop test	Wetting and drying test	Abrasion test
	Perforation time (minutes)	Percentage of lost material after fifth cycle (%)	Coefficient of abrasion (gr/cm^2)
B2-1	7:52	/	/
B2-2	12:33	34.4	/
B2-3	/	/	0.16
B2-4	/	/	0.13
B2-5	11:31	31.2	0.13
B2-6	12:48	19.5	0.14
B2-7	15:27	15.0	0.12
B2-8	/	16.0	/
B2-9	12:20	13.4	0.15
B2-10	/	53.2	/
B2-11	/	26.4	/
B2-12	10:32	61.0	/
B2-13	10:43	32.5	0.24
B2-14	12:28	25.7	/
B2-15	10:44	46.1	0.15
B2-16	/	/	/
B2-17	17:10	17.3	0.15
B2-18	19:28	10.9	0.09
B2-19	/	15.6	/
B2-20	10:59	16.7	/
B2-21	13:03	33.2	0.16
Average	**12:41**	**27.5**	**0.15**
K	12.57	/	0.19

Fig. 18. Buddhist temple II. Wetting and drying after the 5th cycle

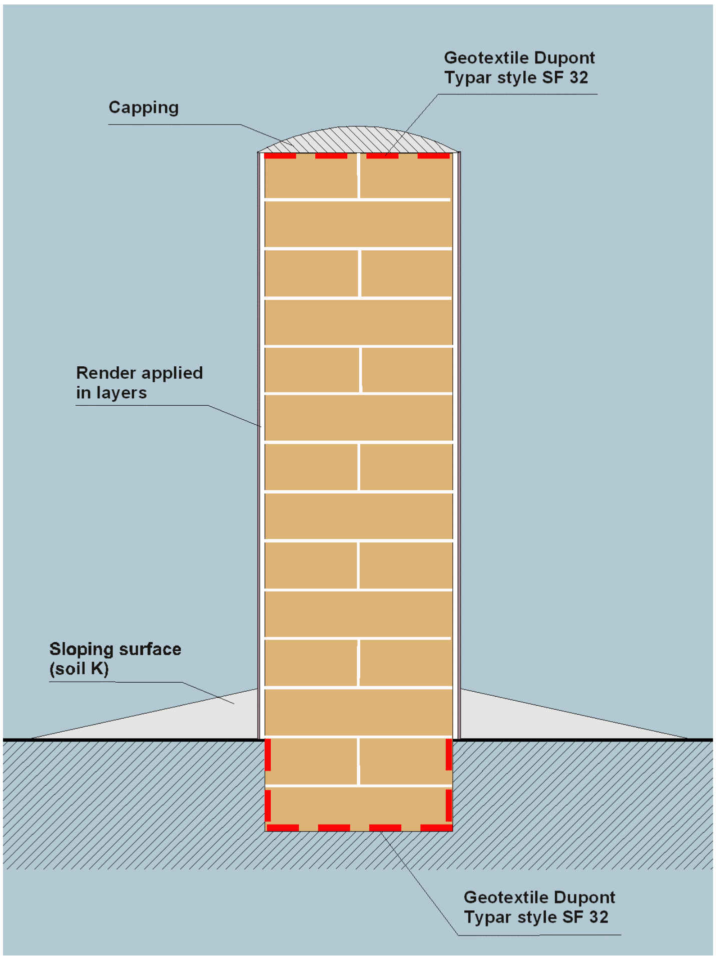

Fig. 19. Test wall representative cross section showing that no foundation was purposely built to accelerate coving effect


Fig. 20. The six test walls after construction. From right to left: TW1, TW2, TW3, TW4, TW5, and TW6

Fig. 21. Three walls were especially built for the testing of plaster under shelter structure condition (picture showing work in progress)

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8. Other religious artifacts excavated in the site include: sculptures from the altar and an icon with Buddha posing in meditation on a lotus.

9. Joints dimensions are varying from 0.8cm to 2cm (horizontal) and from 0.9cm to 1.3cm (vertical)

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13. Work carried out under the supervision of John Hurd

14. See similar method in Fodde, E. (2006)

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16. The procedures adopted here are standard. An explanation of the tests (Soil colour, soluble salts content, carbonates content, measurement of pH, particle size distribution, and Atterberg limits) can be found in two textbooks. See Teutonico, JM (ed.). *International Architectural Conservation Course Laboratory Manual*. ICCROM, Rome (1985). See also Clifton, J and Wencil Brown, P. *Methods for Carachterizing Adobe Building Materials*, US Department of the Interior, National Park Service, Washington DC (1978)

17. A more precise explaination of the role of carbonates is provided by Oliver, A. *Fort Selden Adobe Test Walls Project. Phase I, Final Report*, Getty Conservation Institute, Los Angeles (2000). On page 15 it is described that 'the light colour of the adobes and soil is due to the presence of calcite, which is a very common constituent in soils in arid regions. Calcite may also act as a cement and add strength to the earthen materials. When calcite-rich soils are wetted during the manufacture of adobe, mortar, or render, some of the calcite dissolves and, as water evaporates, reprecipitates. As the pores of the earthen material become unsaturated, water becomes limited to thin films on the grain surface and, due to capillary forces, to constrictions where grains contact one another. As drying continues, the pore water solution becomes supersaturated with respect to calcite and eventually calcite precipitates, cementing the grains together. Calcite in the soil may also stabilise the clay minerals because calcium ions from the dissolution of calcite inhibit the swelling of clays'.

18. Clifton, J and Wencil Brown, P. *Methods for Carachterizing Adobe Building Materials*, US Department of the Interior, National Park Service, Washington DC (1978)

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21. The chemical compositionof the historic mud brick of the Buddhist Temple II is: SiO_2 (53.33%), Al_2O_3 (12.91%), Fe_2O_3 (4.51%), CaO (7.85%), SO_3 (0.41%), NA (0.12%). The chemical composition of the possible repair material (K) is: SiO_2 (54.46%), Al_2O_3 (12.56%), Fe_2O_3 (4.30%), CaO (7.74%), SO_3 (0.55%), NA (0.08%).

22. Apart from the shrinkage test, the methods explained here are not standard because they were dictated by the lack of more sophisticated laboratory facilities in Kyrgyzstan. However, they are considered as adequate especially for the conservation of archaeological sites in remote areas.

23. By comparison with Clifton, J and Wencil Brown, P (1978) 27

24. Test walls were designed after reading the relevant literature on the topic such as Agnew, N. *Adobe Preservation. Report on a Three Month Research Project at the Getty Conservation Institute, Dec 1986 - Feb 1987*, Getty Conservation Institute, Los Angeles (1987). Another useful report was that by Oliver, A. *Fort Selden Adobe Test Walls Project. Phase I, Final Report*, Getty Conservation Institute, Los Angeles (2000). For further information see also Agnew N, Selwitz C, and Demas M. *Reburial Research: Preliminary Field Experiments at Fort Selden*. Conservation and Management of Archaeological Sites **6** (3 and 4) (2004) 333-346

25. The steps that were followed for the moulding of bricks are:

- Soaking of mould in water;

- Application of plastic sheets on the mould faces to improve release of bricks;
- Throwing of clay mixture into the mould. This was done following the traditional method in use in Central Asia, consisting of the throwing of a 'loaf' of mud in the mould, so that to fill it entirely at once. Compaction of corners and eventual scraping of excess mud;
- Pulling of filled mould with a string up to moulding area. In so doing the clay mix is vibrated and the pores space consequentially reduced (density is therefore improved);
- Rotating the mould and lifting to allow dropping of bricks on the ground;
- Drying.

26. Exact location is: UTM 43 T (zone), northing 4749109 m, easting 0498448 m

27. The selection of plasters was dictated after studying NA Kovalova's Report on Quantitative Analysis of Plaster and Soil Samples from the Buddhist temple II. The description of plasters in Kovalova's report were confirmed after interviewing Valentina Goryacheva, the archaeologist who excavated several areas of the Buddhist temple II. It was thus clear that the historic coating of the temple was a complex system of several layers and that the materials employed varied according to the location in the temple itself. The final mix for the plaster was designed with Bubuzura Assakunova after undertaking laboratory tests in the Construction Department, Faculty of Engineering, University of Bishkek.